SUSTAINABLE HOUSING RESETTLEMENT MODEL IN SOUTHERN BRAZIL: ECONOMIC AND ENVIRONMENTAL ASSESSMENT

MODELO DE REASSENTAMENTO HABITACIONAL SUSTENTÁVEL NO SUL DO BRASIL: AVALIAÇÃO ECONÔMICA E AMBIENTAL

MODELO DE REASENTAMIENTO HABITACIONAL SOSTENIBLE EN EL SUR DE BRASIL: EVALUACIÓN ECONÓMICA Y AMBIENTAL

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ABSTRACT
Social inequality often forces vulnerable populations to occupy high-risk areas, compromising their well-being and degrading the environment. This study proposed a sustainable housing model for the residents of the Passo Fundo community in Lages, Santa Catarina, who currently occupy a flood-prone area irregularly. The proposed model is based on a modular house equipped with rainwater harvesting systems, photovoltaic panels, and solar collectors. Economic feasibility was analyzed, and the model was environmentally compared to conventional housing options. The results demonstrated that implementing one or more green technologies aligns with the housing financing criteria, making it accessible to the target population. The environmental impact analysis highlighted the severe negative impacts associated with the residents' current conditions, but showed a substantial reduction in these impacts with the adoption of the proposed model. Ultimately, the study successfully presented a social housing model that balances environmental and economic aspects, offering a practical solution for improving living conditions in vulnerable communities.

KEYWORDS
Social housing; Economic viability; Green technologies; Environmental impact.

RESUMO
A desigualdade social frequentemente obriga as populações vulneráveis a ocupar áreas de alto risco, comprometendo o seu bem-estar e degradando o meio ambiente. Este estudo propôs um modelo de habitação sustentável para os moradores da comunidade Passo Fundo em Lages, Santa Catarina, que atualmente ocupam uma área propensa a inundações de forma irregular. O modelo proposto é baseado em uma casa modular equipada com sistemas de aproveitamento de águas pluviais, painéis fotovoltaicos e coletores solares. A viabilidade econômica foi analisada e o modelo foi comparando ambientalmente com opções habitacionais convencionais. Os resultados demonstraram que a implementação de uma ou mais tecnologias verdes se alinha com os critérios de financiamento habitacional, tornando-o acessível à população-alvo. A análise de impacto ambiental destacou os graves impactos negativos associados às condições atuais dos moradores, mas mostrou uma redução substancial destes impactos com a adoção do modelo proposto. Por último, o estudo apresentou com sucesso um modelo de habitação social que equilibra os aspectos ambientais e econômicos, oferecendo uma solução prática para melhorar as condições de vida em comunidades vulneráveis.

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PALAVRAS-CHAVE
Habitação de interesse social; Viabilidade econômica; Tecnologias verdes; Impacto ambiental.

RESUMEN
La desigualdad social con frecuencia obliga a las poblaciones vulnerables a ocupar áreas de alto riesgo, comprometiendo su bienestar y degradando el medio ambiente. Este estudio propuso un modelo de vivienda sostenible para los residentes de la comunidad Passo Fundo en Lages, Santa Catarina, quienes actualmente ocupan de forma irregular una zona propensa a inundaciones. El modelo propuesto se basa en una casa modular equipada con sistemas de aprovechamiento de aguas pluviales, paneles fotovoltaicos y colectores solares. Se analizó la viabilidad económica y el modelo fue comparado ambientalmente con opciones habitacionales convencionales. Los resultados demostraron que la implementación de una o más tecnologías verdes se alinea con los criterios de financiamiento habitacional, lo que lo hace accesible para la población objetivo. El análisis de impacto ambiental destacó los graves impactos negativos asociados a las condiciones actuales de los residentes, pero mostró una reducción sustancial de estos impactos con la adopción del modelo propuesto. Finalmente, el estudio presentó con éxito un modelo de vivienda social que equilibra los aspectos ambientales y económicos, ofreciendo una solución práctica para mejorar las condiciones de vida en comunidades vulnerables.

PALABRAS CLAVE
Vivienda de interés social; Viabilidad económica; Tecnologías verdes; Impacto ambiental..

1. INTRODUCTION

Environmental problems do not affect urban spaces uniformly, disproportionately impacting areas occupied by low-income populations. The combination of social vulnerability and inadequate urban management often results in irregular settlements in high-risk zones. These areas are characterized by greater exposure to unhealthy living conditions and insalubrity (Pembi et al., 2022), air pollution (Gordon et al., 2014; Jbaily et al., 2022), energy poverty (Kolokotsa and Santamouris, 2015), and thermal discomfort (Tubelo et al., 2018). Additionally, residents face heightened vulnerability to environmental hazards such as flooding and landslides (Tate et al., 2021; Chen et al., 2021; Rentschler et al., 2022).

In Brazil, this issue is particularly acute, with approximately 11 million housing units failing to provide adequate living conditions (Tubelo et al., 2018). The lack of urban planning forces poorer populations to occupy risk areas, such as slopes and riverbanks, in a disorderly manner (Soares et al., 2022). This often leads to a reduction in vegetation, increased vulnerability to environmental disasters, and a decline in quality of life.

Addressing this challenge requires the promotion of housing programs that go beyond simply providing shelter. These programs must offer opportunities for social inclusion by incorporating sustainable and adequate infrastructure into their designs. As discussed by Vasconcelos et al. (2024), flexibility and functionality are critical components in social housing projects, enabling them to meet the specific needs of residents while optimizing the performance and usability of the residences. Similarly, the development of residential projects adapted to local climatic conditions and designed to harness natural resources, such as sunlight and rainwater, can significantly improve the environmental quality and sustainability of social housing.

In this context, this study proposes a sustainable low-income housing model, specifically designed for socially vulnerable families living in high-risk areas. Using a community in southern Brazil (Passo Fundo, Lages/SC) as a case study, the research evaluates the model's economic feasibility and environmental impact, comparing it to both the families' current housing conditions and existing popular housing projects.

2. THEORETICAL FRAMEWORK

Green buildings offer numerous advantages, including reduced consumption of natural resources, mitigation of environmental impacts, improved indoor environmental quality, and minimized site disturbances (Kim et al., 2020). However, in the context of sustainable housing for low-income populations, it is crucial to address the economic dimension. Such housing must not only be affordable but also financially advantageous, as its feasibility often relies more on economic considerations than on ecological motivations.

The financial benefits of low-income green buildings are evident in several areas. For instance, they can lead to significant reductions in energy costs (Zhao et al., 2018) and lower water tariffs (Zocolotti and Haus, 2015). These examples highlight how sustainability and economic efficiency can coexist, demonstrating a positive relationship between environmental responsibility and financial viability.

Case studies worldwide have highlighted the critical role of green materials and technologies in low-income housing, showing expressive results in terms of sustainability and feasibility (Zocolotti and Haus, 2015; Tubelo et al., 2018; Zhao et al., 2018; Lee and Shepley, 2020; Windapo et al., 2021). However, their implementation faces notable barriers and challenges, including limited access to technology, low social acceptance, uncertainty, economic feasibility and restrictive government policies (Kim et al., 2020; Alhassan et al., 2022). Additionally, broader issues, such as the inexperience of casual laborers, the complexity of green technologies, and frequent design changes have been also identified as critical factors negatively impacting the productivity of green projects, when compared to traditional constructions methods (Hwang et al., 2017).

In Brazil, environmental certifications, such as LEED, often fail to align with local realities. Standardized certification criteria frequently overlook regional specificities, as observed in the Amazon, where abundant water availability undermined water efficiency in sustainable buildings (Magalhães et al., 2024). On the financing front, the "Minha Casa Minha Vida" program, launched in 2009, has been one of the most impactful initiatives in reducing Brazil's housing deficit for low-income populations. However, budgetary limitations for individual housing units often result in projects that lack proper environmental considerations, leading to overcrowded and poorly ventilated spaces (Liaw et al., 2023).

Furthermore, the program's participant selection predominantly prioritizes financial eligibility, neglecting critical factors such as precarious living conditions and exposure to environmental risks. Over 7 million Brazilians are estimated to reside in areas vulnerable to landslides, floods, and flash floods. For this population, public initiatives typically focus on identifying and mapping high-risk zones, issuing warnings, and developing emergency response plans (Saito et al., 2019). When relocation is necessary, it is usually managed by state or municipal authorities with limited resources, making it even more challenging to integrate sustainable practices into these initiatives.

3. METHODS

The community of Passo Fundo, located in Lages/SC, Brazil (Figure 1) was selected as the case study for this research. This location was chosen due to its high susceptibility to flooding, which has made it the focus of a relocation project led by the municipality. Lages/SC, with an average population of 160,000 inhabitants, is situated within the Caveiras river basin and serves as the primary economic hub of the southern plateau of Santa Catarina. Geographically, it is positioned at approximately 27°49' south latitude and 50°20' west longitude, with an average altitude of 940 meters. The main urban core spans roughly 88 km² (Cordeiro e Rafaeli Neto, 2015).

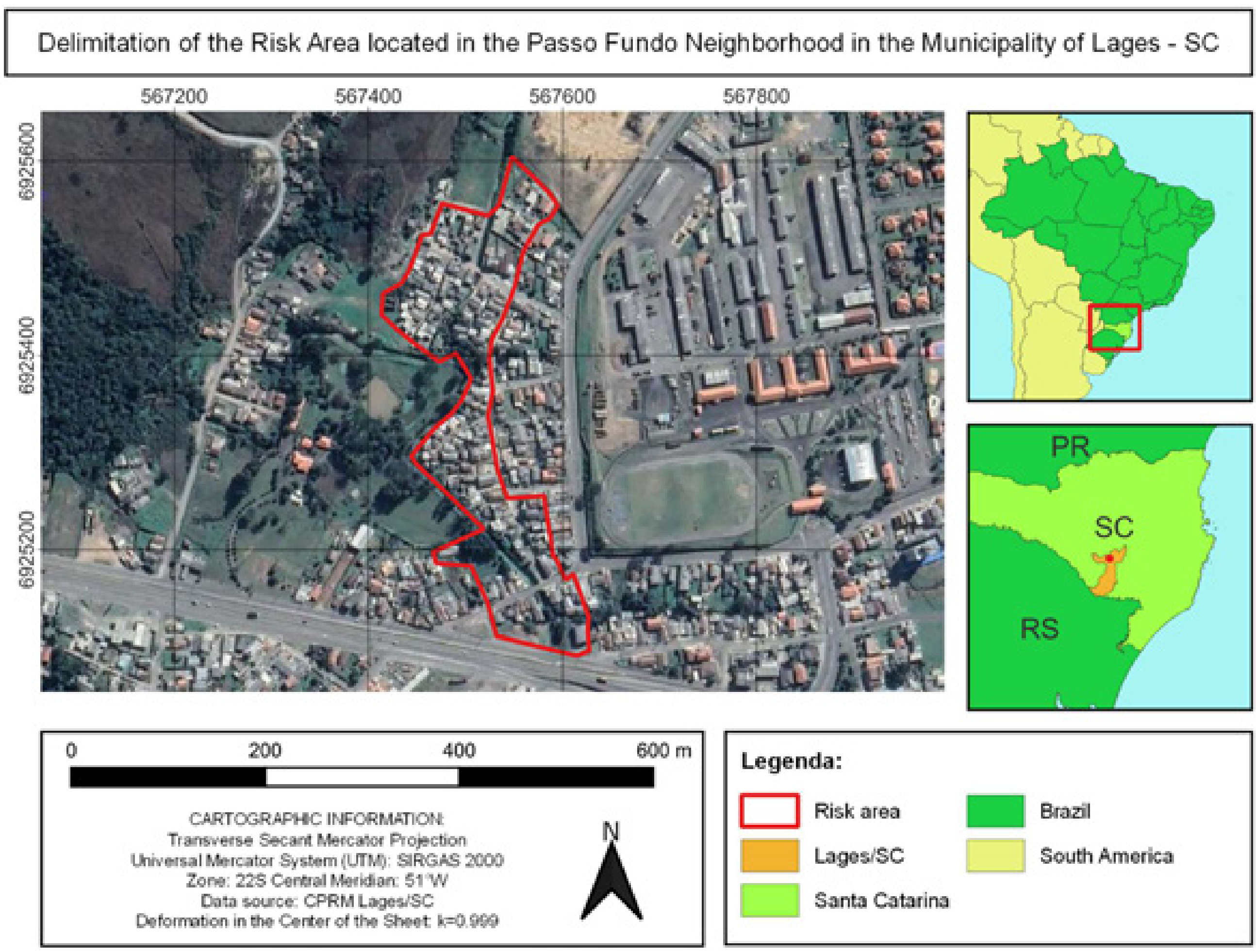

Figure 1: Delimitation of the area with high risk of mass movements, flooding and inundations in the case study area.
Source: CPRM (2022).

According to historical data from the Lages meteorological station (1941 to 2014), the region experiences an average monthly rainfall of 128.4 mm, with all months recording precipitation levels above 100 mm. The highest rainfall occurs in September, October, and January, while the lowest is observed in April, May, and June. The annual average rainfall is 1,540.3 mm.

A survey conducted by CPRM (2022) revealed that the urban occupation of the Passo Fundo community is concentrated along the banks and floodplain of the Passo

Fundo stream, rendering it highly prone to seasonal flooding. In lower-lying areas, water accumulation from these events can persist for up to seven days, as recorded during intense rains in 2017. Local residents report that flooding occurs at least once a year (Figure 2), exacerbated by human interventions, such as bridge construction and bank narrowing due to urban growth.

Figure 2: Images of the Passo Fundo stream, (A) before and (B) after the flood.
Source: The authors.

The CPRM report also highlighted the precarious infrastructure of the area, including unpaved roads, inadequate rainwater drainage systems, and the use of cesspool and sanitary filters for sewage management. The degree of risk was classified as very high, with approximately 163 houses and 652 people affected by flooding hazards.

To address this issue, this study employed a standard modular house model (Fischer, 2020) with a total area of 39.41 m^2, comprising two bedrooms, a bathroom, and a combined living room and kitchen. The single-story house is constructed using sandwich-type panels for the structure of the walls and roof, each consisting of two pre-painted galvanized steel sheets with a 60 mm layer of polyisocyanurate (PIR), that provides both structural support and insulation. This design offers enhanced acoustic and thermal comfort, aligning with the study's goals.

Additionally, modifications were made to optimize the model for rainwater harvesting systems, solar thermal collectors, and photovoltaic panels, further enhancing its environmental and functional performance.

3.1. Rainwater harvesting system

The implementation of a rainwater harvesting system allows pluvial waters to be used in non-potable applications. In this project, the collected water was allocated for specific purposes, such as washing machine usage (one cycle every three days), toilet flushing (34 L/inhabitant/day for a four-person household) and internal and external house cleaning, with monthly water demands of 1,085; 4,080; and 600 L/month, respectively. These estimates were based on average water consumption in residential settings (CASAN, 2022).

The system was dimensioned using the Australian method, following NBR 15527 (ABNT, 2007). The volume of rainwater collected was calculated by considering the catchment area, surface runoff coefficient, and average monthly precipitation at the study site. Pipeline diameters for the cold-water network, reservoir connections, and the rainwater reservoir were determined using the Hunter method, as specified in NBR 5626 (ABNT, 1998). Additionally, the power requirements for the pumping system were calculated to ensure proper operation.

3.2. Water solar-heating system

To design the solar thermal system, the hot water demand for the residence was estimated based on an average household size of 3.7 inhabitants. The calculations for sizing the solar collector were performed according to NBR 15569 (ABNT, 2020). The temperature parameters used included 40°C for consumption water, 50°C for storage, and 16°C as the average room temperature for Lages, based on historical meteorological data.

The collectors were positioned for optimal solar capture, oriented towards the geographic north and inclined at an angle of 37º to the horizontal plane. The average global solar irradiation for the site was 4.42 kWh/m^2.day (CRESESB, 2018).

3.3. Photovoltaic solar system

The residential electricity demand was estimated based on the average electricity consumption of the target population and the current tariff provided by the local electricity distribution company.

The on-grid photovoltaic system was dimensioned considering the local average peak sun hours (PSH) of 4.42 h/day, derived from solar irradiation data. Potential losses due to shading, dirt, and temperature effects were disregarded. The photovoltaic modules were also positioned for optimal solar exposure throughout the year, oriented towards the geographic north and inclined at 32º to the horizontal plane.

3.4. Economic feasibility analysis

An economic feasibility analysis was conducted for the modular residence equipped with proposed sustainable technologies. This analysis aimed to evaluate the affordability of the final model for the target audience and compared the cost savings generated by standard and low-income residences. Additionally, the performance of individual technologies was analyzed alongside the integrated system through cash flow comparisons.

The analysis employed standard economic evaluation methods, including Net Present Value (NPV), Internal Rate of Return (IRR), Payback period and Benefit-Cost Ratio.

3.5. Environmental impact analysis

An environmental impact matrix was developed to evaluate the implementation and occupation phases of three scenarios: (a) a conventional brick residence; (b) the proposed sustainable residence model; (c) the current irregular and at-risk housing situation (only during the occupation phase).

The analysis consisted of four stages: (1) identification of activities during the implementation and occupation phases for each housing model; (2) identification of environmental impacts associated with these activities; (3) qualitative and quantitative evaluation of impacts based on the following criteria: nature (positive or negative), magnitude, and reach; (4) comparative matrix analysis.

For the present study, impacts were categorized as either: (a) positive/beneficial, enhancing economic, social, or environmental factors, thus improving quality of life and environment conditions; (b) negative/adverse, deteriorating economic, social, or environmental factors, leading to environmental degradation and reduced quality of life.

Magnitude is defined as the extent of environmental change, and is classified as: (a) low (level 1), corresponding to insignificant impacts; (b) medium (lvl 2), for moderate impacts; and (c) high (lvl 3), for significant impacts.

Reach is referred to the spatial and temporal extent of consequences, and is classified as: (a) low (lvl 1), for localized impacts and effects up to 3 months; (b) medium (lvl 2), for non-permanent impacts and effects up to 3-6 months; and (c) high (lvl 3), for extensive and permanent impacts, with effects lasting beyond 6 months.

To streamline the analysis, common activities between the conventional and sustainable residence models, such as land clearing, construction site setup, earthworks, and utility installation, were excluded from the matrix for a clearer focus on the distinct impacts of each model.

4. RESULTS AND DISCUSSION

The original modular design was modified (Figure 3) to integrate the proposed sustainable technologies. A single-pitched roof was implemented to optimize rainwater collection, and wet areas were centralized to simplify water system connections.

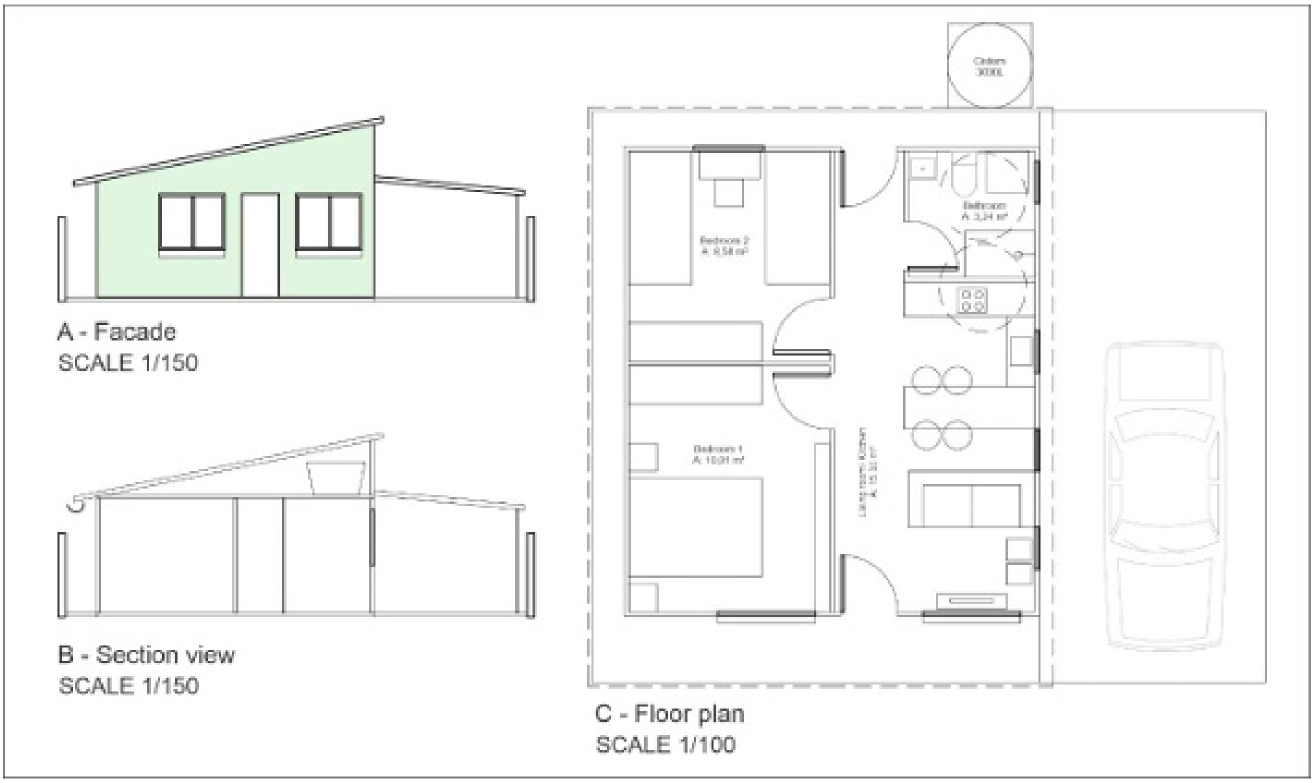

Figure 3: Proposed house model. (A) Facade, (B) section view, and (C) floor plan.
Source: The authors.

4.1. Rainwater harvesting system

To dimension the rainwater reservoir, the total water demand for all activities was considered alongside the 54.4 m² collection area and the rainfall historical series of Lages. Collected rainwater values were compared with monthly demand to determine periods of overflow and calculate the ideal reservoir size. The optimal reservoir capacity was determined to be 3,000 L, based on the correlation between demand and accumulated collection.

To ensure water quality, a first flush system was included, discarding the initial 21.76 L of rainwater to remove impurities. This volume was calculated using the roof area (54.4 m²), a rainfall height of 0.5 mm, and a runoff coefficient of 0.8.

The system's pump was designed to overcome a dynamic head of 3.8 m, requiring a power of 0.05 HP. As this value was unavailable commercially, a submersible pump of 370 W with a maximum lifting capacity of 70 meters was selected. To ensure uninterrupted operation, a backup pump was included, along with two electric float switches to prevent pump activation during insufficient water levels and to avoid overflows in the upper reservoir.

4.2. Water solar-heating system

To estimate the solar thermal system requirements, a daily hot water demand of 400 L was calculated based on four individuals showering for 20 minutes each. A commercial 400 L thermal reservoir (Heliotek) with 2,500 W heating capacity, measuring 170 cm in length and 68 cm in diameter, was selected.

The energy required by the solar collectors was determined to be 15.79 KWh, necessitating a collection area of 4.32 m². A flat-plate solar collector (Heliotek MC1300) was chosen, with dimensions of 1 m x 2 m and an average daily energy production of 4.66 KWh/m². Three collector plates were needed to meet the demand.

4.3. Photovoltaic solar system

The average monthly electricity expense of the Passo Fundo community was R$ 94.88, corresponding to an average consumption of 237.304 KWh/month, based on a tariff of R$ 0.40/KWh for low-income residences (CELESC, 2022).

A 3,000 W commercial inverter (GROWATT MIC 3000TLX) with 97.6% efficiency was selected. The photovoltaic modules, made of polycrystalline silicon, had a capacity of 340 W and 17.2% efficiency (BYD 340P6K-36). Six photovoltaic modules were required to meet the energy demand of 1.50 kWh/day, occupying 11.64 m^2 of roof area.

4.4. Sustainable household model

By combining all proposed systems, a sustainable low-income residence model was developed, integrating a rainwater harvesting system, solar water heating, and photovoltaic panels. Figure 4 illustrates the model with these technologies.

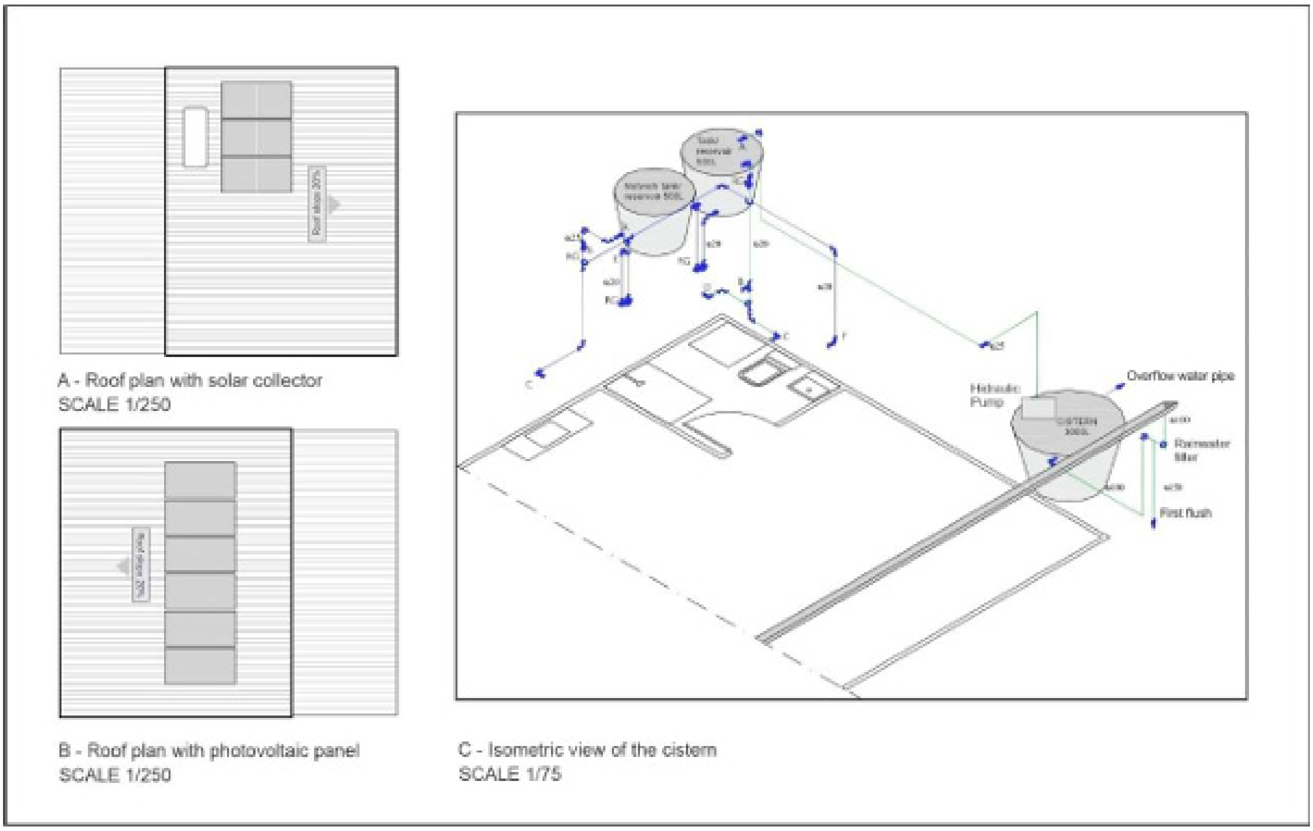

Figure 4 : Sustainable residential model with proposed technologies. (A) Roof plan with solar collector; (B) roof plan with photovoltaic panel; and (C) isometric view of the cistern.
Source: The authors.

4.5. Economic feasibility analysis

The economic analysis focused on the modular sustainable residence, aiming to determine whether the final cost aligns with the financing capabilities of the target audience. This analysis also compared the savings generated in standard and low-income residences, evaluating the performance of the technologies both individually and when integrated as a system.

4.5.1. Rainwater harvesting system

According to the National Sanitation Information System (SNIS, 2022), the average daily consumption per inhabitant is 200 liters. For a household of four residents, this corresponds to an average water consumption of 800 L/day (24 m^3/month).

In Lages, the municipal water supply concessionaire applies a minimum tariff for conventional residences of R$ 31.36 and R$ 5.91 for social residences, covering up to 10 m^3 of water. For consumption exceeding this amount, a rate of R$ 5.33/m^3 is charged for conventional residences, while social residences are charged R$ 1.50 m^3, up to 25 m^3. Based on these rates, the monthly water bill for a conventional residence with a consumption of 24 m^3 is R$ 105.98, while for a social residence is R$ 27.05.

The installation of a rainwater harvesting system, capable of collecting 5,765 liters per month, would reduce treated water consumption from 24,000 liters to 18,235 liters per month, representing a 24% reduction. This decrease in consumption would lower the monthly water bill to R$ 75.25 for conventional residences and R$18.34 for social residences.

With the proposed system, conventional residences could achieve a 29% reduction in their water bill, resulting in savings of R$ 30.73 per month (or R$ 368.76 annually). For social residences, the reduction would be 32.2% leading to savings of R$ 8.71 per month (or R$ 104.52 annually).

4.5.2. Water solar-heating system

According to the National Electrical Energy Conservation Program (PROCEL, 2022), a standard electric shower of 5500 W consumes approximately 165 KWh/month for a family of four. Energy tariff rates provided by CELESC are R$ 0.5059/KWh for conventional residences and R$ 0.40/KWh for low-income residences. Based on these rates, the annual cost of using an electric shower is R$ 965.64 for a conventional residence, and R$ 792.00 for a low-income residence.

4.5.3. Photovoltaic solar system

According to consumption data provided by CELESC for the period from January 2018 to September 2020, the average electricity consumption per inhabitant in the municipality of Lages is estimated at 66.097 KWh/month. For a family of four, this equates to an average monthly consumption of 265.345 KWh for standard residences and 237.304 KWh for low-income residences. Based on the respective electricity tariffs, the monthly electricity cost is calculated at R$ 133.73 for conventional residences and R$ 94.92 for low-income residences.

By implementing photovoltaic modules, significant savings can be achieved in both scenarios. The quoted photovoltaic module has an expected average monthly production of 223 KWh, resulting in a remaining consumption of 41.345 KWh/month for conventional residences and 14.30 KWh/month for low-income residences. This translates into monthly savings of 84.36% (R$ 1,353.84 annually) for conventional residences and 93.97% (R$ 1,070.40 annually) for low-income residences.

4.5.4. System costs and feasibility

The total implementation costs were:

- Rainwater system (pipeline + 2 pumps + 2 reservoirs + installation) = R$ 6,152.82.
- Solar collector system (3 collectors + boiler + installation) = R$ 6,275.72.
- Photovoltaic system (6 pv panels + inverter + installation) = R$ 9,970.00.

A 15-year cash flow analysis was conducted to evaluate the economic performances of the systems. Table 1 summarizes the results for key economic indicators, including Payback, IRR, NPV and Cost-Benefit Ratio, for both individual and integrated systems.

Systems	Indicators	Conventional residence	Low-income residence
Rainwater harvesting Water	Payback	20.45 years	69.05 years
	TIR	-1,30%	-13.60%
	VPL	-R$ 14,139.53	-R$ 4,808.81
	B/C ratio	0.75	0.214
Water solar-heating	Payback	7.03 years	8.72 years
	TIR	13.60%	11.20%
	VPL	R$ 7,297.78	R$ 6,232.37
	B/C ratio	2.162	1.772
PV (photovoltaic) solar	Payback	9.05 years	11.38 years
	TIR	12%	8.60%
	VPL	R$ 10,388.99	R$ 6,746.99
	BC/ ratio	2.02	1.64

Systems	Indicators	Conventional residence	Low-income residence
Rainwater harvesting + Water solar-heating	Payback	10.41 years	14.79 years
	TIR	7.40%	3.40%
	VPL	R$ 5,884.26	R$ 1,307.23
	B/C ratio	1.44	1.001
Rainwater harvesting + PV solar	Payback	9.95 years	15.48 years
	TIR	8.60%	3.30%
	VPL	R$ 9,688.05	R$ 1,835.71
	B/C ratio	1.53	1.098

Table 1: Economic analysis of individual and integrated systems.
Source: The authors (2020).

The rainwater harvesting system was found to be economically unfeasible when implemented individually across all scenarios, likely due to the relatively low water consumption tariffs.

Conversely, systems related to solar energy, specifically the solar collector and photovoltaic modules, yielded positive economic outcomes. The results further suggest that the installation of solar energy systems is particularly advantageous for conventional residences, where energy tariffs are higher compared to those for low-income households.

When applied in an integrated manner, the solar collector and photovoltaic panels make the implementation of the rainwater system economically feasible, enabling their combined application. However, due to differences in tariff rates, the economic benefits are more significant for conventional residences.

The total cost of implementing modular houses, including materials and labor, is R$ 79,768.03. The costs of modular residences with the addition of sustainable technologies, whether applied individually or in an integrated manner, are as follow:

- Modular house with rainwater harvesting system = R$ 85,919.85
- Modular house with water solar-heating system = R$ 85,143.85
- Modular house with PV solar system = R$ 89,738.03
- Modular house with rainwater harvesting + water solar-heating = R$ 91,295.67
- Modular house with rainwater harvesting + PV solar = R$ 95.889,85

The cost of implementing these systems does not exceed R$ 96,000.00, demonstrating the feasibility of incorporating sustainable technologies that provide financial returns. Considering the average family income of the target audience, these modular houses fall within the Minha Casa Minha Vida social program's range 1 financing criteria. Under this program, the government subsidizes 90% of the property's value, with the remaining 10% payable in up to 120 monthly installments, ranging from R$ 80 to R$ 270, without interest. With a maximum property value of R$ 96,000.00 for this range, the proposed options align with the program's financing conditions (MDR, 2020).

4.6. Environmental impact analysis

An environmental impact matrix (Figure 5) evaluated physical, biotic and socioeconomic factors during the installation and occupation phases of conventional, sustainable, and current housing scenarios.

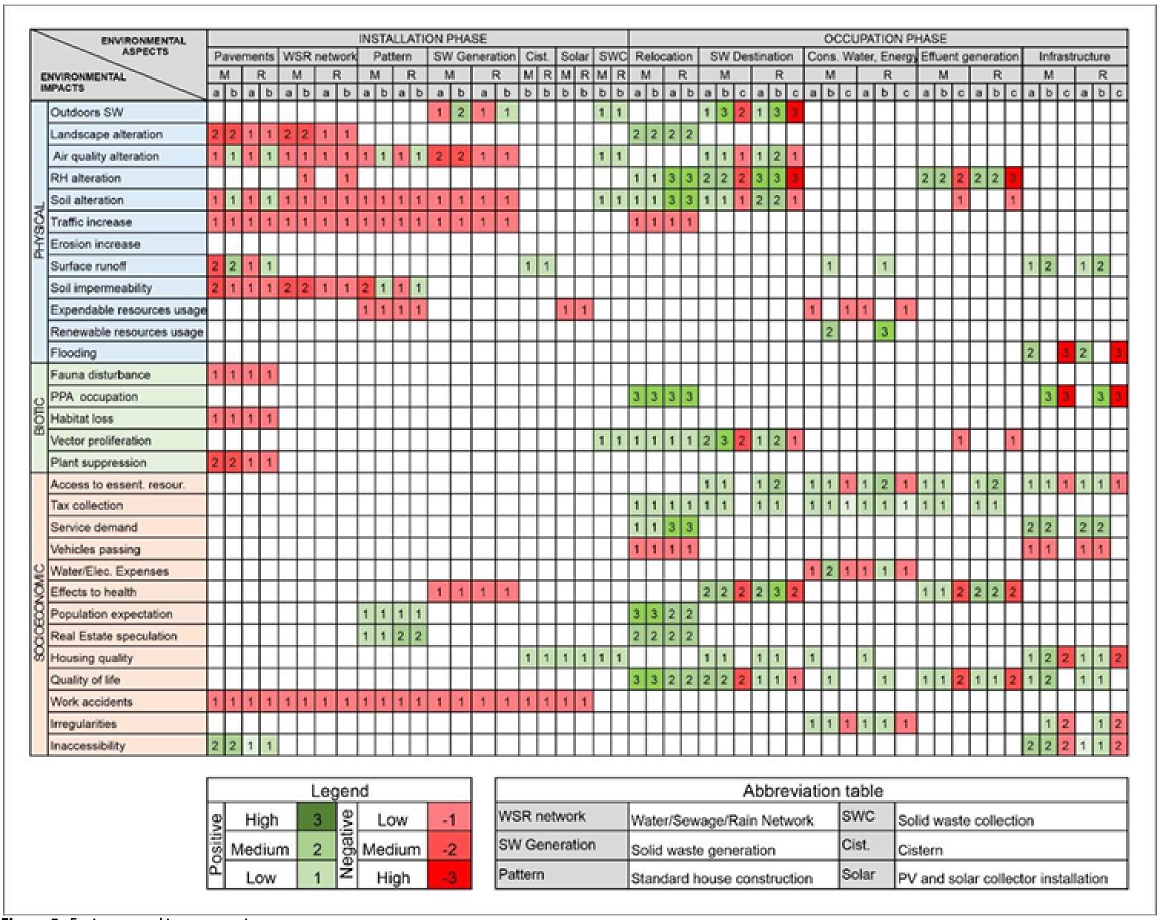

Figure 5 : Environmental impact matrix.
Source: The authors.

The current scenario revealed significant negative impacts in both magnitude and scope, far exceeding those observed in residential models, whether or not they incorporate sustainable technologies. This is primarily due to the precarious living conditions faced by the Passo Fundo community, which include open garbage disposal, sewage discharge into the river, irregular occupation of Permanent Preservation Areas (PPA) with high flooding risks, inadequate infrastructure, and the resulting adverse effects on residents' health and quality of life.

Figure 6 presents the results of the environmental impact analysis, comparing the current population scenario, the conventional housing model, and the sustainable housing model that integrates the proposed green technologies (rainwater harvesting + water solar-heating + photovoltaic solar).

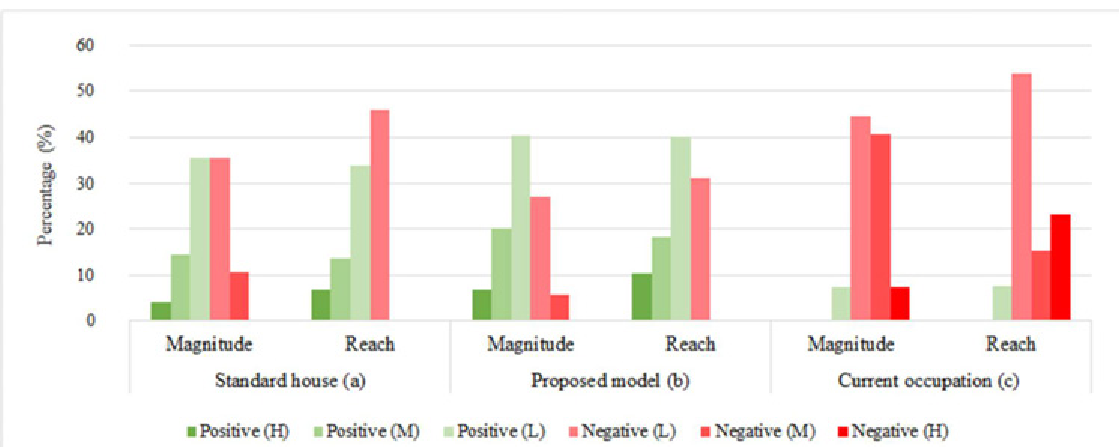

Figure 6 : Environmental impact analysis for the three proposed scenarios.
Source: The authors.

Among the residential models, the sustainable housing proposal demonstrated a significant increase in positive impacts and a reduction in negative impacts compared to the conventional model. This improvement is primarily attributed to lower waste generation during the construction of modular houses, the use of renewable resources, and reduced water and energy consumption from external networks.

5. CONCLUSION

This study demonstrated the feasibility and advantages of implementing sustainable technologies in housing models for low-income populations in flood-prone areas. While the inclusion of these technologies increases the initial investment, the long-term reduction in monthly expenses makes the model economically viable, particularly for families with limited income.

The economic analysis revealed the importance of integrating systems, as the combined application of the rainwater harvesting system with either the photovoltaic panel or solar collector ensured financial feasibility. Moreover, the total cost of the proposed model remained within the limits of the Minha Casa Minha Vida social program, enabling broader access to sustainable housing solutions.

The environmental impact analysis further validated the proposed model, showcasing its ability to reduce negative impacts and enhance positive contributions to the environment, health, and quality of life. By addressing current challenges such as waste disposal, inadequate infrastructure, and flooding risks, the sustainable model represents a comprehensive solution for improving living conditions in vulnerable communities.

In conclusion, this study highlights that integrating sustainable technologies into low-income housing is not only viable but also essential for promoting social inclusion, economic efficiency, and environmental preservation. These findings underscore the need for public policies and financing mechanisms that support the adoption of sustainable housing models on a larger scale.

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